FIRE DANGER / FIRE BEHAVIOR COMPUTATIONS WITH THE TEXAS INSTRUMENTS TI-59 CALCULATOR:

USER'S MANUAL

Robert E. Burgan

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FOREWORD

Development of a custom program for predicting fire behavior on a hand-held calculator represents an attempt to condense years of fire research by many individuals into a convenient tool for field application. Like any tool, its usefulness will grow as experience is gained.

The Texas Instruments TI-59 calculator equipped with a custom-designed chip can be used to calculate either the National Fire Danger Rating System indices or values of rate of spread, intensity, and other measurements used by Fire Behavior Officers (FBO) or fire planners. The two systems utilize different sets of fuel models. These two sets of fuel models have evolved to meet the requirements of the two different methods of application.

The NFDR System is designed to appraise the fire potential developing from weather patterns that occur during a fire season. The System applies to broad areas and represents fire conditions in exposed fuels on southwest slopes; that is, it assumes what are usually the most severe conditions. The fuel models and calculation procedures were specifically designed to reflect the seasonal variability of fire severity in both large and fine fuels. For instance, many of the NFDR fuel models have a living fuel component whose moisture variation over the season can be adjusted according to the general climate of an area. The fine fuel load is then internally transferred between the live and dead categories in response to seasonal fluctuations in the moisture content of the live fuels.

In addition, the NFDR System is designed to reflect the effect of large fuels (1000 hour timelag) on some aspects of fire behavior. These larger fuels contribute strongly to the Energy Release Component and the Burning Index. The NFDRS computations require a lot of information about the climate so that the calculations can be made automatically. The NFDR System is thus better adapted for routine calculations with much less training than is required for specific fire behavior assessments.

The fire behavior predictions system, by contrast, is designed to be used on a small scale ahead of an actual fire. The ratio of live to dead fuel is set for the time of year when fires can be severe. This system relies on considerable judgment on the part of the user to correctly determine fuel types, fuel moisture, slope, and wind along the fire front. Fires usually spread by one or more "runs", which occur when all conditions are right. During these runs, the fine fuels carry the fire. The procedures and fuel models used in fire behavior programs are designed to reflect this characteristic. Large fuel components are purposely left out of the fire behavior fuel models.

After you learn to operate the calculator with both programs, you will find that because of fewer inputs the Fire Behavior program is much simpler to use than the Fire Danger program. This may be somewhat deceiving, however, because not all procedures for projecting fire growth are accommodated within the TI-59 program. Methods for predicting mid-flame windspeed and adjusting fuel moistures for aspect, elevation, and canopy cover for different times of the day, year, and at different latitudes must precede program operation. Training is required to interpret the expected fire growth, plot it on a map, and interpret severe fire behavior. To properly use the Fire Behavior program, one should have had this training.

Fire Behavior is an extremely complex phenomenon and it cannot be expected that all the answers can be packed into a black box no matter how sophisticated it becomes. We can expect, however, that a new generation of "fire experts" who have learned to interpret conditions and utilize the latest technology and training will emerge, and become highly skilled at applying their knowledge to specific fire management situations.

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RESEARCH SUMMARY

A fire danger/fire behavior Custom Read Only Memory (CROM) has been developed for the Texas Instruments model 59 hand held calculator. This battery operated calculator can be used in either office or field situations to compute both 1978 National Fire Danger Rating (NFDR) indexes and components and several variables used to estimate wildfire behavior. Calculations can be performed in three operational modes: 1) compute NFDR indexes and components from standard NFDRS weather observations, 2) compute NFDR indexes and components using direct entry of live and dead fuel moistures, 3) perform computations required by fire behavior officers.

CONTENTS

INTRODUCTION

The fire danger/fire behavior Custom Read Only Memory (CROM) developed for the TI-59 calculator computes both 1978 National Fire Danger Rating (NFDR) indexes and components (Deeming and others 1977), and several of the variables used to estimate wildfire behavior. This CROM replaces all the nomograms for manually calculating NFDRS indexes and components (Burgan and others 1977) and many of the nomograms for estimating fire behavior (Albini 1976). It can perform calculations for three operational modes: 1) compute NFDR indexes and components from standard NFDRS weather observations, 2) compute NFDR indexes and components using direct entry of live and dead fuel moistures, and 3) perform fire behavior computations.

LIMITATIONS

Mathematical Fire Model

The fire behavior programs contained in the CROM are based on the fire model developed by Rothermel (1972) and are therefore subject to the limitations and assumptions specified for that model.

The fire model was designed for fires that are burning steadily in surface fuels, such as grass, brush, timber litter, and so on. The model was not designed to predict the behavior of crown fires or the influence of spot fires on fire growth. It will, however, predict when fire intensity in surface fuels is becoming severe enough to cause crowning and spotting. The fire model predicts the behavior at the fire front and assumes that the fire is burning along a line. It will not work for burning piled fuels or for predicting burnout behind the fire front. It is assumed the fire has travelled far enough so the method of ignition no longer influences behavior and that it is not impeded by fire suppression activities. Use for prescribed burning must take this into account. Fire behavior from strip firing or perimeter ignition can be quite different from the steady state condition but can be related with experience. If burning conditions are so marginal that a steady flame cannot be sustained, the model will not predict the behavior as the fire creeps through the duff and litter.

The fire model will work best in uniform fuels such as grass, long needle pine litter, clearcut slash and chaparral. Fire behavior in nonuniform fuels such as those found in many forests, particularly on mountain slopes, is more difficult to predict.

National Fire Danger Rating

The TI-59 Calculator will reduce the tedium of manual NFDRS calculations with the following limitations:

1. The calculator is not intended to replace or reduce the use of the AFFIRMS system. Automatic archiving of weather data in the National Fire Weather Library (Furman and Brink 1975), an important AFFIRMS service, is not possible with the TI-59. Use of the NFDR System for fire planning requires this long-term weather data.

2. The TI-59 is not efficient for processing large volumes of historic weather data. Thus, it neither replaces, nor provides a substitute for, the FIRDAT program (Furman and Helfman 1973).

3. Reliable fire danger ratings can be calculated only with the 20 fuel models developed for the 1978 NFDR System.

4. The TI-59 has no capability to retain data from day to day. Switching the calculator OFF erases all data entered. It was not possible to carry station data from day to day on magnetic cards because data entered from a station card would replace previously entered fuel model data. Thus, the user must manually re-enter station data each day.

5. The procedure required to exactly match the 1000-hour timelag fuel moisture (1000-H TL FM) calculation in FIRDAT and AFFIRMS would have resulted in extreme user inconvenience if applied to the TI-59. The simplified procedure used can result in slightly different 1000-H TL FM, X1000 values, and moisture content for herbaceous and woody fuels. However, the magnitude of the differences was tested and found to be a reasonable trade-off for user convenience.

6. Relative humidity is required rather than dewpoint or dry bulb and wet bulb temperatures.

7. Fuel-stick moisture must be adjusted for effects of stick aging.

8. The AFFIRMS and FIRDAT programs can compute fire danger ratings with various combinations of weather data. However, such flexibility was not attainable with the TI-59 program. All the weather inputs asked for are required.

Fire Behavior

1. Not all the graphs and tables typically used by a fire behavior officer are programmed into the CROM. Specifically, windspeed is assumed to be at midflame height; therefore, any adjustments required to reduce a 20-foot windspeed to midflame height, or to adjust it for the effects of vegetation or topography, must be done externally.

2. Although the CROM can calculate 1-hour timelag fuel moisture (1-H TL FM) from temperature, relative humidity, and cloudiness data measured on site, supplementary tables are required to determine this value for other locations.

3. Scorch height and spotting distance calculations are not programmed into the CROM.

4. The fuel models that can be used for fire behavior calculations are the 13 NFFL models described in "Estimating Wildfire Behavior and Effects" (Albini 1976). These are programmed into the CROM. Fuel models developed in the future can be entered via magnetic cards.

OPERATIONAL AIDS

Several items accompanying the TI-59 are necessary for operating the fire danger and fire behavior programs.

1. Separate plastic keyboard overlays are provided for fire danger and fire behavior. The overlays define the inputs and label the keys for entering individual data items. Labels are written above the keys to which they apply. Place the appropriate overlay on the keyboard and secure it with a small piece of tape.

Certain labels are printed on the face of the keys. Throughout this manual, the key labels will be enclosed in a rectangle: 2nd SBR R/S,...while NFDRS labels such as latitude (LAT), lightning risk scaling factor (LRSF), etc., will be identified as LAT, LRSF, and so on.

2. A plastic strip (5/8" x 3") is included that shows where to obtain fire behavior outputs. When running fire behavior, slip this card through the slot in the upper right side of the calculator so it appears in the space between the top row of keys and the display window. This strip defines the outputs obtained from keys A , B , C , D , and E immediately below the labels.

3. 1978 NFDRS fuel model cards can be obtained from the TI-59 program coordinator for your area. Each fuel model is recorded twice on each card--once on each side.

4. The 13 NFFL fuel models used for fire behavior are programmed into the CROM and can be accessed as explained in the section--CALCULATING FIRE BEHAVIOR.

NFDRS COMPUTATIONS FROM WEATHER DATA

Recording Form

Fire danger computations from weather data are keyed to the 10-Day Fire Danger and Fire Weather Record (Form D9b). However, because this form was designed long before the TI-59 was anticipated, not all TI-59 entries are labeled. Specifically, latitude, lightning risk scaling factor, and the number of days since the vegetation began greening up, i.e., "green days", are not labeled. Label these as LAT, LRSF, and GD in the unlabeled columns A, B, and C on the lower right corner of the form.

Definition of Inputs

The most common mode of operation will be to calculate fire danger indexes and components from weather data recorded at basic observation time and fuel moistures carried forward from the previous day. The suggested order of entry, keyboard abbreviation, item description, and location on form D9b are shown in the following tabulations.

ORDERED LIST FOR NFDRS WEATHER DATA OPTION

Entry	Data item label	Data item	Location on form D9b
1	LAT	Station latitude	Previously entered in column A
2	LRSF	Lightning risk scaling factor	From column B
3	GD	Green days	Column C. Prior to greening or after a freeze use 0. Enter 1 on the day green-up begins, 2 on the second day of green-up, 3 on the third and so on. Continue entering successively higher numbers until both herbaceous and woody vegetation go dormant as a result of a freeze, drought, or seasonal cycle; then use 0 again.
4	VEGT	Vegetation type	From D9b header information. Use 1 for annuals, 0 for perennials.
5	SLP C	Slope class	From D9b header
6	CC	Climate class	From D9b header
7	MD	Month and day	Column 1. Enter as a decimal value. For example, key in June 1 as 6.01 or June 15 as 6.15.
8	SW	State of the weather	Column 2
9	DB	Observation time dry bulb temperature	Column 3
10	RH	Relative humidity	Column 5. Relative humidity must be entered directly; it cannot be calculated from wet bulb temperature.
11[1]	OFS	Observed fuel sticks	Column 6. If not known, enter 0.
12	WS	Windspeed (in mph)	Column 12
13	YLOI	Yesterday's lightning occurrence index	Previous day's value from column 18. Use 0 for first day of calculations.
14	MRSK	Man-caused risk	Column 19. Determine as instructed in The National Fire-Danger Rating System--1978 (Deeming and others 1977) and enter the value for today.
15	MX T	Maximum temperature	Column 23
16	MN T	Minimum temperature	Column 24
17	MX RH	Maximum relative humidity	Column 25
18	MN RH	Minimum relative humidity	Column 26
19	PD	Precipitation duration	Column 31
20	LAL	Lightning activity level	Column 35
21	YM100	Yesterday's 100-H TL FM	Yesterday's value from column 36. For the first day's calculations use 10, 15, 20, or 25 for climate classes 1, 2, 3, or 4, respectively.
22	YM1000	Yesterday's 1000-H TL FM	Yesterday's value from column 40. For the first day's calculations use 15, 20, 25, or 30 for climate classes, 1, 2, 3, or 4, respectively.
23	YX1000	Yesterday's X1000 value	Yesterday's value from column 42. For the first day's calculations use the value for YM1000 as described above.
24	YHRB	Yesterday's herbaceous moisture	Yesterday's value from column 43. For the first day's calculations use 10.

[1]10-H TL FM will be calculated if a 0 is entered. However, neither the calculated value nor a measured value will be corrected for stick age.

Operating Instructions

SELECTING THE NFDRS PROGRAM AND ENTERING FUEL MODEL DATA

Slide the ON/OFF switch (located on extreme upper left corner of the calculator) to the ON position and single 0 will appear in the display.

Select the NFDRS program with the following sequence of keystrokes: 2nd , PGM, 1 , SBR , R/S . The number 4. will appear in the display.

Choose the appropriate fuel model card. Handle the card carefully by its edges, and insert it into the lower slot on the right side of the calculator. Do not restrict its advance once it is caught by the drive motor. The display will go blank briefly, then the number 4. will appear after the fuel model card has been read. Pull the card out of the calculator.

If a flashing display results, press CLR , check to be sure you have a valid 1978 NFDRS fuel model card, select the NFDRS program again, and reinsert the card. If the display still flashes, the card may be dirty, resulting in a misread. Before trying to read it again, gently wash the card with warm water and a small amount of mild detergent. If it still will not read, order a new card. Misreads can also occur when operating with batteries that are nearly discharged.

After a successful read, press R/S and a number 1. will appear in the display.

ENTERING STATION AND WEATHER DATA

Station and weather data can be entered either sequentially or in random order. To enter data sequentially, start at the top of the ordered list described previously and enter the value for each successive item. That is, key in latitude, the first item in the ordered list, and press SBR LAT. This will store the latitude and position the program pointer for entry of the next item in the list, namely LRSF. Then enter the value for LRSF and press R/S . Continue by keying in the value for each successive item in the list, pressing R/S after each entry. The last entry (number 24) is yesterday's herbaceous moisture (YHRB).

Data can also be entered in random order, or the ordered list entered at any point, by keying in a valid number, pressing SBR and then the key below the appropriate data item label. This will store the value entered and position the program pointer for entry of the next item in the list. However, if this procedure is used, you *must always:* 1) key in the value so it appears in the display, 2) press SBR , 3) press the key below the DATA ITEM LABEL. Failure to press the SBR key can result in an error that may not be immediately obvious and can be corrected only by turning the machine off and starting all over.

CORRECTING ERRONEOUS DATA ENTRIES

If an erroneous number has been keyed into the display, finish entering that number as though it were a valid entry. Then enter the correct value in the display and press SBR and the DATA ITEM LABEL that corresponds to the item being corrected. For example, assume that LAT, LRSF, GD, and VEGT have been entered correctly, but that the wrong slope class (SLP C) was entered. The calculator now expects the next entry

to be climate class (CC) because that is the next item on the list. To correct the slope class, key in the proper number and press [SBR] SLP C. This will move the program pointer back to slope class, store it, and reposition the pointer for entry of climate class.

CHECKING THE INPUT DATA

Prior to running the program, you may want to check some or all of the input values. Use of the [2nd] key permits the same NFDRS labeled key to be used for data recall as was used for data entry. Again, you can either start at any point in the ordered NFDRS Weather Data Option list and proceed sequentially through it, or randomly access the list to check individual items. For example, to start at the beginning of the list and check each item, press [SBR] [2nd] LAT and the value entered for latitude will appear in the display. From this point, the remainder of the items will appear in sequence by repeatedly pressing [R/S] . This general procedure may be used to check any individual entry in the list by pressing [SBR] [2nd] DATA ITEM LABEL and then, if desired, the remainder of the items in the list by pressing [R/S] repeatedly.

OBTAINING AND RECORDING NFDRS OUTPUTS

After all the station and weather data has been entered and checked, press [2nd] [A] to begin the calculations.

Because the NFDRS program is designed specifically for Form D9b, the outputs are keyed to the column numbers of the form. The display will flash a number, designating the column in which the next answer is to be recorded. The value to be recorded will *not* flash. For example, after pressing [2nd] [A], a flashing 7 will appear. This is the column number in which 10-H TL FM is to be recorded. Press [R/S] to obtain the actual value to record.[2] Press [R/S] again and an 8 will flash. Press [R/S] and record the 1-H TL FM in column 8. Continue pressing [R/S] and record each answer in the column designated by the flashing display. The procedure is designed so you must record the value of all items to be carried over to the next day (columns 36, 40, 41, 42, 43) before obtaining any NFDR indexes or components. The last value displayed will be the fire load index. If it is necessary to check any answers, the same data can be reprocessed by pressing [2nd] [A] and a series of [R/S] . Alternatively, answers can be recalled directly by pressing [RCL] [X] [X] where [X] [X] is a two digit register number. See appendix B for the list of variables and their register numbers.

To process successive days of weather data, or to change one or more items in the current day's weather input list without altering the others, first press [2nd] PGM [1] [SBR] [R/S] , then enter the new data. For example, to change windspeed (WS) and run the program again, press [2nd] PGM [1] [SBR] [R/S] , key in the new windspeed, and press SBR WS. After this change, the revised outputs are calculated by repeating the output procedure. That is, [2nd] [A] , then a series of [R/S].

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[2] If a 10-H TL FM value was input, that same value will be output, except that it will never be less than 2. If the 10-H TL FM was entered as 0, a calculated value will appear.

A WORKED EXAMPLE

Calculate fuel moistures and the NFDRS indexes and Components using the station and weather data provided in the following example. This same example is worked on Form D9b (fig. 1) to illustrate use of this form with the program. The inputs are printed in standard type, the outputs in italics.

Step	Procedure	Enter	Press	Display
1	Turn calculator on			0
2	Select NFDRS program		[2nd] PGM [1] [SBR] [R/S]	4.
3	Enter NFDR fuel model card	Model G card		4.
4	Check fuel model compatibility		[R/S]	1.
5	Enter latitude (LAT)	49	[SBR] LAT	49.
6	Enter lgt. risk scaling factor (LRSF)	1	[R/S]	1.
7	Enter green days (GD)	22	[R/S]	22.
8	Enter veg. type (VEGT)	0	[R/S]	0.
9	Enter slope class (SLP C)	3	[R/S]	3.
10	Enter climate class (CC)	3	[R/S]	3.
11	Enter month and day (MD)	6.22	[R/S]	6.22
12	Enter state of weather (SW)	2.	[R/S]	2.
13	Enter dry bulb (DB)	87	[R/S]	87.
14	Enter relative humidity (RH)	31	[R/S]	31.
15	Enter stick moisture (OFS)	10	[R/S]	10.
16	Enter windspeed (WS)	1	[R/S]	1.
17	Enter yes. lgt. occ. index (YLOI)	2	[R/S]	2.
18	Enter man risk (MRSK)	15	[R/S]	15.
19	Enter max. temp, (MX T)	90	[R/S]	90.
20	Enter min. temp. (MN T)	48	[R/S]	48.
21	Enter max. RH (MX RH)	99	[R/S]	99.
22	Enter min. RH (MN RH)	28	[R/S]	28.
23	Enter precip. dur. (PD)	0	[R/S]	0.
24	Enter lgt. activity level (LAL)	2	[R/S]	2.
25	Enter yes. 100 H TL FM (YM100)	13.58	[R/S]	13.58
26	Enter yes. 1000 H TL FM (YM1000)	18.19	[R/S]	18.19
27	Enter yes. X1000 value (YX1000)	18.07	[R/S]	18.07
28	Enter yes. herb moisture (YHRB)	143	[R/S]	143.

Step	Procedure	Enter	Press	Display
29	Obtain col. no. for 10 H TL FM		[2nd] [A]	Flashing 7
30	Obtain 10 H TL FM		[R/S]	10.
31	Obtain col. no. for 1 H TL FM		[R/S]	Flashing 8
32	Obtain 1 H TL FM		[R/S]	6.
33	Obtain col. no. for 100 H TL FM		[R/S]	Flashing 36
34	Obtain 100 H TL FM		[R/S]	13.27
35	Obtain col. no. for 1000 H TL FM		[R/S]	Flashing 40
36	Obtain 1000 H TL FM		[R/S]	17.94
37	Obtain col. no. for woody moisture		[R/S]	Flashing 41
38	Obtain woody moisture		[R/S]	137.
39	Obtain col. no. for X1000 value		[R/S]	Flashing 42
40	Obtain X1000 Value		[R/S]	17.82
41	Obtain col. no. for herb moisture		[R/S]	Flashing 43
42	Obtain herb moisture		[R/S]	139.
43	Obtain col. no. for SC		[R/S]	Flashing 13
44	Obtain SC		[R/S]	3.
45	Obtain col. no. for ERC		[R/S]	Flashing 14
46	Obtain ERC		[R/S]	32.
47	Obtain col. no. for BI		[R/S]	Flashing 15
48	Obtain BI		[R/S]	26.
49	Obtain col. no. for IC		[R/S]	Flashing 16
50	Obtain IC		[R/S]	16.
51	Obtain col. no. for lgt. risk		[R/S]	Flashing 17
52	Obtain lgt. risk		[R/S]	12.
53	Obtain col. no. for LOI		[R/S]	Flashing 18
54	Obtain LOI		[R/S]	5.
55	Obtain col. no. for MCOI		[R/S]	Flashing 20
56	Obtain MCOI		[R/S]	2.
57	Obtain col. no. for FLI		[R/S]	Flashing 21
58	Obtain FLI		[R/S]	19.

WS FORM D-9b (1-78) PRES. BY WSOM D-06	U.S. DEPT. OF COMMERCE NOAA NATIONAL WEATHER SER.	AGENCY	UNIT	STATION NAME	STATION NUMBER
10 DAY FIRE DANGER AND FIRE WEATHER RECORD		FOREST SERVICE	LIBBY DISTRICT	LIBBY	240107

STATION ELEVATION	FUEL MODEL	ANNUAL OR PERENNIAL	SLOPE CLASS	CLIMATE CLASS	BASIC OBS TIME (LST)	PERIOD OF RECORD (MONTH, DAY, YEAR) FROM	TO
2070	G	P (O)	3	3	1400	6/20/78	6/30/78

OBSERVER

CHECKED BY

Day of month	State of weather	Temperature: Dry bulb	Temperature: Wet bulb	Temperature: Dew point (degrees)	Relative (%) humidity	Observed fuel sticks	10-hr TL fuel moisture	1-hr TL fuel moisture	Herb. veg. condition	Fine fuel moisture	Burning Index: Wind: Direction	Burning Index: Wind: Speed	Burning Index: Spread component	Burning Index: Energy release component	Burning Index	Occurrence Indexes: Ignition component	Occurrence Indexes: Lightning risk	Occurrence Indexes: Lightning occurrence index	Occurrence Indexes: Man-caused risk	Occurrence Indexes: Man-caused occurrence index	Fine load index	Remarks
1	2	3	4	4a	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
21																		2				
22	2	87			31	10	10	6				1	3	32	26	16	12	5	15	2	19	
23																						
24																						
25																						
26																						
27																						
28																						
29																						
30																						
31																						

Day of month	Daily (24 hour) data: Temperature: Maximum	Temperature: Minimum	Relative humidities: Maximum	Relative humidities: Minimum	Relative humidities: Average	Precipitation: Kind	Precipitation: Began	Precipitation: Ended	Precipitation: Duration	Precipitation: Amount	Lightning: Began	Lightning: Ended	Lightning: Activity level	100-hr TL fuel moisture	1000-hr TL fuel moisture: Today's 1000-hr. bnd ry value	Average 7-day bnd ry value	Change 1000-hr fuel moisture	1000-hr TL fuel moisture	Living fuel moistures: Woody fuel moisture	X1000 moisture value	Herb. fuel moisture				
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	A	B	C	D
21														13.58				18.19		18.07	143	LAT	LRSS	GO	
22	90	48	99	28					0				2	13.22				17.94	137	17.82	139	49	1	22	
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31																									

WS FORM D-9B (1-78)

Figure 1.--Sample NFDRS computation form and worked example.

When the fire season has progressed to the point that the herbaceous fuels have cured, but the live woody fuels are not dormant (green days (GD) is not zero) today's herbaceous moisture will equal the value entered for yesterday's herbaceous moisture. This does not affect the index and component calculations.

Because the slash fuel models (models I, J, and K) have no live fuel, zero may be entered for green days, vegetation type, climate class, yesterday's X1000 value, and yesterday's herbaceous moisture. Then ignore the values calculated for herbaceous and woody fuel moisture and for the X1000 value.

If the values calculated for lightning risk and lightning occurrence index will not be used, enter zero for the lightning risk scaling factor, yesterday's lightning occurrence index, and the lightning activity level.

If the man-caused occurrence index is not needed, enter zero for man-caused risk.

NFDRS COMPUTATIONS FROM DIRECT MOISTURE INPUTS

NFDR indexes and components can be calculated from direct fuel moisture inputs and a limited amount of station and weather data, rather than from the standard weather data, if desired. The purpose is to provide a "game-playing" flexibility for research, training, or planning. For instance, you may want to know what the NFDR indexes and components would be, given assumed values for live and dead fuel moistures. Additional flexibility in selecting outputs is also available with this option.

Definitions and Entry of Inputs

The inputs required for this option depend on the desired outputs. The following table specifies the minimum data required to obtain particular NFDRS indexes and components. Each index or component requires all the inputs used previously plus those listed for the specific index or component. That is, the LIGHTNING RISK and LIGHTNING OCCURRENCE INDEX require all the data needed to compute SC, ERC, BI, and IC *plus* the LIGHTNING RISK SCALING FACTOR, YESTERDAY'S LIGHTNING OCCURRENCE INDEX and the LIGHTNING ACTIVITY LEVEL. Entry of the fuel model data is assumed.

DATA LIST FOR NFDR DIRECT MOISTURE OPTION

NFDR output	Data required	Data entry
Spread component (SC) Energy release component (ERC) Burning index (BI) Ignition component (IC)	State of weather	SW
	Slope class	SLP C
	Windspeed	WS
	1-H TL FM	1 H
	10-H TL FM	OFS
	100-H TL FM[3]	100 H
	1000-H TL FM[3]	1000 H
	Herbaceous FM[3]	HERB
	Live Woody FM[3]	WOOD
	Dry bulb temp	DB
Lightning risk and lightning occurrence index	Lightning risk scaling factor	LRSF
	Yesterday's lightning occurrence index	YLOI
	Lightning activity level	LAL
Man-caused occurrence index and fire load index	Man-caused risk	MRSK

Direct entry of the 1-H TL FM sets a flag that tells the calculator to assume *all* the required moistures will be entered directly. Thus, all moisture calculations are skipped and the first number to appear is the Spread Component. However, after the flag has been used, it is turned off by the program. THEREFORE, YOU MUST *ALWAYS* ENTER THE 1-H TL FM TO TURN THE FLAG BACK ON, *EVERY* TIME YOU USE THIS OPTION.

Values for the 1-H, 100-H, 1000-H, HERB and WOOD moistures require one additional keystroke for both entry and recall. To enter one of these values, key the number into the display, then press SBR 2nd and the key below the DATA ITEM LABEL in brackets, for example, [HERB].

Use of this option does not permit entering data in an ordered list; therefore, you *cannot* select a starting point and use the R/S key for the remainder of the entries. YOU MUST ALWAYS key the number into the display and press SBR DATA ITEM LABEL for any items also in the weather data list or SBR 2nd DATA ITEM LABEL for the direct moisture inputs. Notice that the labels for the direct moisture inputs all reference the number keys on the TI-59 keyboard. Erroneous entries of these items can be changed by keying the correct number into the display and pressing SBR 2nd DATA ITEM LABEL. To recall one of these entries, press SBR 2nd and the key below the DATA ITEM LABEL in parentheses, for example (HERB).

[3]These moistures required only when the fuel model being used has fuel loads in the corresponding classes.

Obtaining and Recording NFDRS Outputs

After the required data has been entered, begin program execution by pressing [2nd][A] . The first number to appear will be a flashing 13, the D9b column number in which to record the value for Spread Component. To obtain the Spread Component, and the remainder of the indexes and components, repeatedly press [R/S] . Remember that because all the fuel moistures were entered, these calculations were skipped.

This option can be rerun by pressing [2nd] PGM [1][SBR][R/S] , re-entering the 1-H TL FM, changing the value of other inputs if desired, then pressing [2nd][A] and a series of [R/S] .

A WORKED EXAMPLE

Calculate the NFDRS Indexes and Components using the direct inputs provided in the following example:

Step	Procedure	Enter	Press	Display
1	Turn calculator on			0
2	Select NFDRS Program		[2nd] PGM [1] [SBR] [R/S]	4.
3	Enter NFDR fuel model card	Model G card		4.
4	Check fuel model compatibility		[R/S]	1.
5	Enter lgt. risk scaling factor (LRSF)	0.8	[SBR] LRSF	0.8
6	Enter slope class (SLP C)	2	[SBR] SLP C	2.
7	Enter state of weather (SW)	0	[SBR] SW	0.
8	Enter dry bulb (DB)	67	[SBR] DB	67.
9	Enter 10 H TL FM (OFS)	8	[SBR] OFS	8.
10	Enter windspeed (WS)	0	[SBR] WS	0.
11	Enter yes. lgt. occ. index (YLOI)	0	[SBR] YLOI	0.
12	Enter man risk (MRSK)	75	[SBR] MRSK	75.
13	Enter lgt. activity level (LAL)	3	[SBR] LAL	3.
14	Enter 100 H TL FM (100 H)	10.63	[SBR] [2nd] [100 H]	10.63
15	Enter 1000 H TL FM (1000 H)	14.87	[SBR] [2nd] [1000 H]	14.87

Step	Procedure	Enter	Press	Display
16	Enter herb moisture (HERB)	20	SBR 2nd [HERB]	20.
17	Enter woody moisture (WOOD)	61	SBR 2nd [WOOD]	61.
18	Press 2nd PGM 3 SBR R/S[4]	Ignore the number that appears		
19	Press 2nd PGM 1 SBR R/S[4]	Ignore the number that appears		
20	Enter 1-H TL FM (1 H)	3.73	SBR 2nd [1 H]	3.73
21	Obtain col. no. for SC		2nd A	Flashing 13
22	Obtain SC		R/S	4.
23	Obtain col. no. for ERC		R/S	Flashing 14
24	Obtain ERC		R/S	47.
25	Obtain col. no. for BI		R/S	Flashing 15
26	Obtain BI		R/S	35.
27	Obtain col. no. for IC		R/S	Flashing 16
28	Obtain IC		R/S	27.
29	Obtain col. no. for lgt. risk		R/S	Flashing 17
30	Obtain lgt. risk		R/S	20.
31	Obtain col. no. for LOI		R/S	Flashing 18
32	Obtain LOI		R/S	10.
33	Obtain col. no. for MCOI		R/S	Flashing 20
34	Obtain MCOI		R/S	20.
35	Obtain col. no. for FLI		R/S	Flashing 21
36	Obtain FLI		R/S	32.

[4]Because this option skips several sub-programs, these steps are necessary to adjust the dry bulb temperature for the state of weather. Therefore, they must be executed whenever either the dry bulb temperature or state of weather are changed.

CALCULATING FIRE BEHAVIOR

Recording Form

The recording form developed for fire behavior officers (FBO) has been revised for use with the TI-59 and to reflect recent changes in FBO calculations. In addition a TI-59 fire behavior planning form has been developed to aid fire planning use. A sample of each form is in appendix D.

Selecting the Fire Behavior Program and A Fuel Model

If the fire danger program has been run previously, always turn the calculator off momentarily to clear the data registers before running the fire behavior program.

Program 2 is designated for fire behavior. Select this program by pressing [2nd] PGM [2] [SBR] [R/S] and a -4. will appear in the display. Because the 13 NFFL fuel models (Albini 1976) are programmed in the CROM, one of these models can now be selected by entering a model number and pressing [R/S]. The display will go blank briefly while the calculator searches for the model and loads the data into several storage registers. The model number entered will then reappear in the display. If an erroneous fuel model is keyed in, the display will flash the number entered. If this happens, press [CLR] and access Program 2 again.

Anticipating that the fire behavior fuel models built into the CROM will eventually be superceded, the program is designed to accept fire behavior fuel models from cards. When such a card becomes available, press [2nd] PGM [2] [SBR] [R/S] to obtain the -4. in the display. Put the fuel model card through the card reader and press [R/S] . The numeral 0 in the display will indicate the fuel model data has been entered.

Definition and Entry of Inputs

The inputs used for fire behavior calculations and their keyboard labels are given in the following tabulation.

FIRE BEHAVIOR INPUTS

Data	Keyboard abbreviation
Shading from clouds or canopy	SHADE
Dry bulb temperature	DB
Relative humidity	RH
1 hour timelag fuel moisture	1 H
10 hour timelag fuel moisture	10 H
100 hour timelag fuel moisture	100 H
Live fuel moisture	LIVE
Midflame windspeed in mph	M WS
Percent slope	PCT S
Projection time in hours	PT
Map scale in inches per mile	MS

Ignition component and 1-H TL FM calculations are affected by the shading of fuels at the fire site. Select the number to adjust for the effect of shading from the following:

Cloud or canopy shading	Shade value
Less than 0.1 cloud cover or no canopy	0
0.1 to 0.5 cloud or canopy cover	1
0.6 to 0.9 cloud or canopy cover	2
Total cloud or canopy cover	3

All the above inputs are mandatory, except relative humidity, which must be entered only if an estimated 1-H TL FM is to be calculated.

Operating Instructions

Unlike the entering of weather data to calculate fire danger indexes, *all* fire behavior inputs must be entered by first keying a number into the display, then pressing [SBR] DATA ITEM LABEL. Any data entry can be recalled by pressing [SBR] [2nd] DATA ITEM LABEL.

If the 1-, 10-, and 100-hour timelag fuel moistures are known, they should be entered directly. However, if they are not known, "on site" measurements of shade, dry bulb temperature, and relative humidity can be used to calculate the 1-, and 10-hour timelag fuel moistures *at that location*. To do this, first be sure the 10-H TL FM is zero by pressing [0] [SBR] 10 H. Otherwise, a previously stored or calculated 10-H TL FM can affect the current calculation. Then enter the shade value, dry bulb temperature, and relative humidity *in that order* and press [R/S] . The 1-H TL FM will be both stored and displayed, while the 10-H TL FM will be stored without display. If that 100-H TL FM is not known, press [SBR] [2nd] 10 H to display the 10-H TL FM, then store that value for the 100-H TL FM by pressing [SBR] 100 H. Dry bulb temperature and the shade value must always be entered because these values are used to calculate the IGNITION COMPONENT. Entry of relative humidity is necessary only when the above procedure is used.

The fire behavior program has no capability to adjust fuel moistures from one site to another. If this is necessary, follow the "DEAD FUEL MOISTURE ESTIMATION PROCEDURE" in the TI-59 Field Reference. Enter the value obtained as 1-H TL FM, but enter zero for both 10- and 100-hour timelag fuel moistures. The 1-H TL FM will automatically be used for all three moistures.

Obtaining Fire Behavior Outputs

The slide in key label card identifies the outputs obtained from keys [A] , [B] , [C] , [D] , and [E] . These keys *must be pressed in sequence* because results of one calculation may be used for the next. When one of these keys is pressed, the number displayed is the value for the upper item on the key label card. The value for the lower item is always obtained by pressing [R/S] .

The following table provides the keystroke sequence to obtain fire behavior outputs.

Output item[5]	Abbreviation	Keystroke
Rate of spread (ch/h)	ROS	A
Heat per unit area (BTU/ft^2)	H/A	R/S
Fireline intensity (BTU/ft/s)	INT	B
Flame length (feet)	FL	R/S
Spread distance (chains)	SD	C
Map distance (inches)	MD	R/S
Perimeter (chains)	PER	D
Area (acres)	AREA	R/S
Ignition component	IC	E
Reaction intensity (BTU/ft^2/min)	IR	R/S

After a run (keys A through E) has been completed for a given set of inputs, an answer may be recalled directly from the register designated in Appendix B by pressing RCL and the two-digit register number or keys A through E may be pressed in sequence again.

One or more input values, including the fuel model, can be changed and the program rerun. For example, if program 2 has been accessed previously, the fuel model can be changed by pressing SBR R/S , entering the new fuel model number and pressing R/S . Or the midflame windspeed can be changed by entering the new value, then pressing SBR M WS. After changing any of the other inputs, press keys A through E in sequence to rerun the program.

A WORKED EXAMPLE

Calculate fire behavior using data provided in the following example:

Step	Procedure	Enter	Press	Display
1	Turn calculator on			0
2	Select Fire Behavior Program		2nd PGM 2 SBR R/S	-4.
3	Select NFFL fuel model	5	R/S	5.
4	Enter shade value (SHADE)	3	SBR SHADE	3.
5	Enter dry bulb (DB)	95	SBR DB	95.
6	Enter relative humidity (RH)	10	SBR RH	10.
7	Calculate 1 H TL FM		R/S	2.33
8	Enter rounded 1 H TL FM (1 H)	2	SBR 1 H	2.
9	Enter estimated 10 H TL FM (10 H)	5	SBR 10 H	5.

[5]The outputs are rounded to whole numbers or to one decimal. To obtain additional significant digits, press INV 2nd (.

Step	Procedure	Enter	Press	Display
10	Enter estimated 100 H TL FM (100 H)	7	SBR 100 H	7.
11	Enter live fuel moisture (LIVE)	75	SBR LIVE	75.
12	Enter midflame windspeed (WS)	4	SBR M WS	4.
13	Enter percent slope (PCT S)	30	SBR PCT S	30.
14	Enter projection time (PT)	1	SBR PT	1.
15	Enter map scale (MS)	2	SBR MS	2.
16	Obtain rate of spread (ROS)		A	32.
17	Obtain heat/unit area (H/A)		R/S	789.
18	Obtain fireline intensity (INT)		B	469.
19	Obtain flamelength (FL)		R/S	8.
20	Obtain spread distance (SD)		C	32.4
21	Obtain map distance (MD)		R/S	0.8
22	Obtain perimeter (PER)		D	102.
23	Obtain area (AREA)		R/S	72.
24	Obtain ignition component (IC)		E	94.
25	Obtain reaction intensity (IR)		R/S	3460.

TROUBLE SHOOTING

The programming capacity of the CROM is not large enough to permit extensive checks of either your inputs or operating procedures. Therefore, if you become hopelessly lost in erroneous numbers and flashing displays, turn the calculator OFF and start from the beginning. Should your difficulties continue, write down your exact procedure and contact your TI-59 area coordinator.

BATTERY CARE

Page A-1 in the Personal Programming Guide supplied by Texas Instruments with the TI-59 specifies proper battery care. Operate the calculator as a portable unit at least twice a month; otherwise, the batteries will lose storage capacity and thus reduce operating time as a portable unit.

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APPENDIX A.

DUPLICATING FUEL MODEL CARDS

The fuel model data on one magnetic card can be recorded on another magnetic card as follows:

1. If your TI-59 is on, turn it off momentarily to be sure all data registers are set to zero.

2. Turn the TI-59 on, press [2nd] PGM [1] [SBR] [R/S] and a 4 will appear in the display.

3. Put the fuel model card to be duplicated through the card reader. This enters the data from that card into several registers in the calculator.

4. Press [2nd] [R/S] and insert the fuel model card being made through the card reader. This transfers the data from the registers in the calculator to the new fuel model card. Turn the new card over and repeat the step so the data will be recorded on both sides.

5. Label the card with the appropriate fuel model letter. Be sure to use a pen with permanent, fast-drying ink. After labeling the card, rub the ink with your finger to be sure the writing does not come off easily. Unstable ink can soil the card reader in TI-59 and cause malfunctions.

APPENDIX B.

DATA STORAGE REGISTERS

Upon completing a full set of fire danger or fire behavior calculations, the input and output data is in the following registers:

Fire Danger Rating

Data item	Reg. no.
LAT	64
LRSF	82
GD	76
VEGT	78
SLP C	80
CC	73
MD	65
SW	60
DB	61
RH	62
OFS	63
WS	79
YLOI	83
MRSK	81
MX T	67
MN T	68
MX RH	69
MN RH	70
PD	71
LAL	84
YM100	66
YM1000	72
YX1000	74
YHRB	77
1 H[1]	28
10 H	63
100 H	30
1000 H	31
WOOD	33
HERB	32
SC	48
ERC	51
BI	49
MCIC	44
LRISK	97
LOI	46
MCOI	45
FLI	50

Fire Behavior

Data item	Reg. no.
SHADE	60
DB	61
RH	62
1 H	28
10 H	63
100 H	30
LIVE	33
M WS	79
PCT S	80
PT	81
MS	82
ROS (ft/min)	48
ROS (ch/h)	88
H/A	90
INT	53
FL	54
SD	42
MD	43
PER	40
AREA	89
IC	44
IR	52

This data can be recalled by pressing RCL and the appropriate register number.

[1]The 1-H TL FM recalled from register 28 will equal the value recorded in column 8 only when the LAL equals 1 or 6.

APPENDIX C.

DEFINITION AND USE OF FIRE BEHAVIOR OUTPUTS

Fire behavior calculations will undoubtedly be performed for a variety of uses, by persons not formally trained as fire behavior officers. Therefore, the outputs and their intended uses are defined as follows:

Output	Definition	Use
Rate of spread (ch/h)	Forward rate of spread of the head fire in chains per hour	Estimate speed at which head fire will progress
Heat/unit area (BTU/ft^2)	The amount of heat released per unit area during the time that unit area is within the flaming front	Used together with rate of spread to approximate fire intensity. See figure 2.
Fireline intensity (BTU/ft/s)	Amount of heat released (in BTU's) per foot of fire front per second	A measure of fireline intensity. See table 1.
Flame length (feet)	Average length of the flame at the head of the fire	An alternate, observable measure of fireline intensity. See table 1.
Spread distance (chains)	An estimate of the probable forward movement of the head of the fire during a specified time period	Estimate position of fire front at some future time
Map distance (inches)	An estimate of the progress of the fire front for mapping purposes	Map the position of fire at some future time
Perimeter (chains)	Perimeter of the fire	Estimate forces needed to control fire
Area (acres)	Size of fire	Estimate size of fire at some future time
Ignition component (no units)	A measure of the probability of spot fires resulting from firebrands	Estimate spotting potential
Reaction intensity (BTU/ft^2/min)	Rate of heat released per unit area per unit time	Research

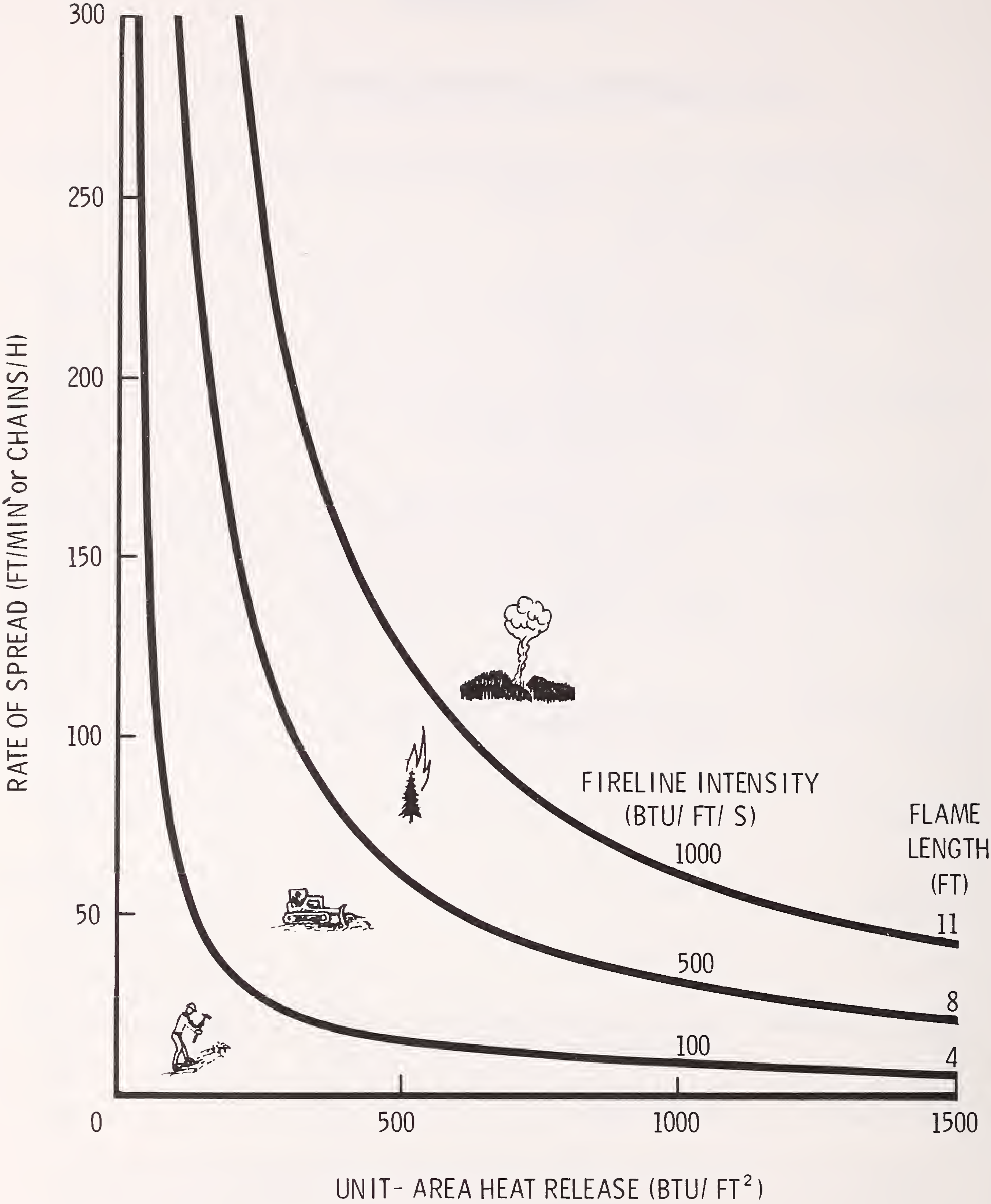

Figure 2.--The potential spread rate and intensity of a fire can be characterized by plotting unit-area heat release and rate of spread.

Table 1.--*Fire suppression interpretations of fireline intensity/flamelength*

Fireline intensity < 100 BTU/sec/ft
Flamelengths < 4 feet

- -fires can generally be attacked at the head or flanks by persons using hand tools.
- -handline should hold the fire.

Fireline intensity 100-600 BTU/sec/ft
Flamelengths 4-8 feet

- -fires are too intense for direct attack on the head by persons using hand tools.
- -handline can not be relied on to hold fire.
- -equipment such as dozers, pumpers, and retardant aircraft can be effective.
- -fires are potentially dangerous to personnel and equipment.

Fireline intensity 500-1000 BTU/sec/ft
Flamelengths 8-11 feet

- -fires may present serious control problems, i.e. torching out, crowning and spotting.
- -control efforts at the fire head will probably be ineffective.

Fireline intensities > 1000 BTU/sec/ft
Flamelengths > 11 feet

- -crowning, spotting, and major fire runs are probable.
- -control efforts at head of fire are ineffective.

APPENDIX D.

SAMPLE FIRE BEHAVIOR RECORDING FORMS

TI-59 FIRE BEHAVIOR PLANNING FORM

Name______________________________ Date____________ Sheet____ of____

Purpose____

Data item	Data item label	TI-59 reg. no.	Values		
INPUT					
Fuel model					
Shade	SHADE	60			
Dry bulb temperature, °F	DB	61			
Relative humidity	RH	62			
1 H TL FM, %	1 H	28			
10 H TL FM, %	10 H	63			
100 H TL FM, %	100 H	30			
Live fuel moisture, %	LIVE	33			
20 foot windspeed, mph					
Midflame windspeed, mph	M WS	79			
Windward percent slope, %	PCT S	80			
Projection time, h	PT	81			
Map scale, in/m	MS	82			
OUTPUT					
A Rate of spread, ch/h	ROS	88			
Heat per unit area, BTU/ft^2	H/A	90			
B Fireline intensity, BTU/ft/s	INT	53			
Flame length, ft	FL	54			
C Spread distance, ch	SD	42			
Map distance, in	MD	43			
D Perimeter, ch	PER	40			
Area, acres	AREA	89			
E Ignition component	IC	44			
Reaction intensity, BTU/ft^2/min	IR	52			

Comments on fuel moisture:

Comments on windspeed:

TI-59 FIRE BEHAVIOR WORKSHEET

Name of Fire ____________ Fire Behavior Officer ____________ Sheet ____ of ____

Date ________ Time ________ Project Period Date ________ Project Time From ________ to ________

Reg.	Rate of spread (ch/h)	Heat/unit area (BTU/ft^2)	Fireline intensity (BTU/s/ft)	Flame length (ft)	Spread distance (ch)	Map distance (in)	Perimeter (ch)	Area (acres)	Ignition component	Reaction intensity (BTU/ft^2/min)
	88	90	53	54	42	43	40	89	44	52

1. Proj. Point ____ Fuel Mod. ____ Day/Night?
2. Shade [ ] DB [ ] RH [ ] Ref.FM ____
3. Aspect ____ Corr. ____ 1 H [ ] 10/100 [ ]
4. Live [ ] 20' WS ____ Dnslp WS Corr. ____
5. Mid-flame WS [ ] Windward PCT S [ ]
6. Proj. Time (H) [ ] Map Sc (in/mi) [ ]
7. Mid-flame WS [0] Flank PCT S [ ]

1. Proj. Point ____ Fuel Mod. ____ Day/Night?
2. Shade [ ] DB [ ] RH [ ] Ref.FM ____
3. Aspect ____ Corr. ____ 1 H [ ] 10/100 [ ]
4. Live [ ] 20' WS ____ Dnslp WS Corr. ____
5. Mid-flame WS [ ] Windward PCT S [ ]
6. Proj. Time (H) [ ] Map Sc (in/mi) [ ]
7. Mid-flame WS [0] Flank PCT S [ ]

1. Proj. Point ____ Fuel Mod. ____ Day/Night?
2. Shade [ ] DB [ ] RH [ ] Ref.FM ____
3. Aspect ____ Corr. ____ 1 H [ ] 10/100 [ ]
4. Live [ ] 20' WS ____ Dnslp WS Corr. ____
5. Mid-flame WS [ ] Windward PCT S [ ]
6. Proj. Time (H) [ ] Map Sc (in/mi) [ ]
7. Mid-flame WS [0] Flank PCT S [ ]

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A fire danger/fire behavior Custom Read Only Memory (CROM) has been developed for the Texas Instruments model 59 hand held calculator can be used to compute both 1978 National Fire Danger Rating indexes and components and several variables used to estimate wildfire behavior. Calculations can be performed in three operational modes.

KEYWORDS: fire danger computations, fire behavior computation,

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
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